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HEDONIC COST FUNCTIONS FOR THE TRUCKING INDUSTRY

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ABSTRACT

In industries where physical output varies with respect to attributes or qualities, it is important to take these differences into account in estimating cost functions. This paper presents a hedonic cost function that can be used to take output characteristics into account and applies it to the regulated trucking industry. It is found that failure to take output characteristics into account creates serious specification error and that inferences concerning economies of scale and factor demand differ substantially between the hedonic and nonhedonic formulation of the cost function.

HEDONIC COST FUNCTIONS FOR THE TRUCKING INDUSTRY

I. Introduction and Overview

There are a large number of technologies that are characterized by multiple outputs with variable qualities or attributes. In such cases, effective output not only depends upon the physical units produced, but also upon the qualities or attributes of these units. Thus, for example, a given number of ton-miles of a given commodity can vary widely in the size of shipment, the length of haul, etc. Therefore, two trucking firms with the same number of ton-miles should have very different effective outputs and costs if one concentrated on short-haul, small-load, less-than-truckload (LTL) traffic and the other concentrated on long-haul, large-load, truckload traffic. Similarly, even if two electrical utilities each produced an identical number of kilowatt hours over the course of a year, their effective outputs and costs would be quite different if one concentrated on serving large industrial users with a variable usage rate and the other concentrated on small residential users with a steady usage rate.

Quality differences are conventionally taken into account by expanding the vector of outputs to encompass the quality dimension. While this approach may be appropriate for commodities with well defined qualities such as TV sets or automobiles, it is not , however, satisfactory for goods characterized by a continuum of qualities. Not only

would the vector of outputs become so large as to make econometric estimation of cost or production functions infeasible, but also if quality is truly continuous, there is no way to define a quality-specific output conveniently. Thus, instead of treating specific quality levels as separate goods, it is more convenient to treat effective output as a function of a generic measure of physical output and its qualities. Therefore, instead of estimating conventional cost functions that use outputs or quality-adjusted outputs in their arguments, it is preferable to estimate hedonic cost functions that use hedonic functions of outputs and qualities as their arguments. This approach not only permits a representation of a class of technologies in which any quality-quantity combination is permitted, but also avoids assumptions required for hedonic deflation, which are unlikely to hold in non-competitive cases.[1/]

This paper reports on an application of a hedonic cost function to the trucking industry, and our findings indicate that omission of qualitative variables is a serious misspecification that induces significant bias. In particular, although conventional econometric estimates of trucking costs, which use a single physical output measure and assume the existence of a homothetic technology, indicate economies of scale, the hedonic cost function indicates that technology is

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[1/] The conventional approach to handling quality differences is to regress price against attributes and then to divide revenues by a quality-adjusted price to obtain a deflated output measure. One problem with this approach, however, is that it assumes quality combinations with identical input requirements sets are sold at identical prices--a condition unlikely to be achieved either in monopolistic competition or under government regulations which simultaneously require different firms to produce different quality combinations and sell at government mandated prices. For a full discussion of these points see Rosen (1973), Lucas (1975), and Spady and Friedlaender (1976).

not homothetic and that the industry is not subject to economies of scale. Thus when the quality or attributes of output are highly variable, quality dimensions should be included in econometric estimates of cost or production functions.

Although this paper applies a hedonic cost function to the trucking industry, it should be applicable to other industries that produce with continuous qualities. All of the transportation industries clearly fall into this category as do electrical utilities, oil refining, etc. Thus the hedonic cost function may well have a wide range of application.

This paper takes the following form. Part II presents a general hedonic cost function with continuous qualities while Part III discusses its application to the trucking industry and its associated econometric results. Part IV presents a brief summary and outlines areas for further research.

II. A General Hedonic Cost Function

Duality theory indicates that every specification of a cost structure corresponds to a specification of a production structure. One can therefore choose to specify a cost function or a production function.[2/] Because, however, it is simpler to specify important and econometrically testable hypotheses concerning the structure of technology by using cost functions, and because production specifications are more likely to violate the assumption of independence of disturbances from independent variables, it is generally more useful to estimate cost functions and their associated factor demand systems.[3/]

The simplest specification that might reasonably be expected to take account of quality differentials is a quality separable hedonic cost function given by

$$\text{Cost} = C[\psi(y,q),w] \tag{1}$$

where $\psi(y,q)$ represents a vector of functions that measure effective outputs and w represents a vector of factor prices. Thus $\psi = \psi^1,\ldots,\psi^n$, and $\psi^i = \psi^i(y_i,q_1^i,\ldots,q_r^i)$, where y_i represents the i^{th} physical output and q_h^i represents the h^{th} quality or attribute

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[2/] See Shephard (1970) for the theoretical equivalence between costs and production and the regularity conditions that are needed to ensure that duality holds.

[3/] See Varian (1975) for a discussion of this problem.

associated with the i^{th} physical output.

We call this cost function "quality-separable" because the effect of quality variations upon the output measure ψ, and therefore on costs, is independent of relative factor prices. The technology implied by such a specification can be envisioned as combining the input factors to produce abstract outputs, measured by ψ^i, which can then be divided into any $(y_i, q_1^i, \ldots, q_r^i)$ combination that satisfies $\psi^i = \psi^i(y_i, q_1^i, \ldots, q_r^i)$. In the case of the trucking industry, this specification implies that factors such as labor, fuel, capital and purchased transportation combine to produce "effective" ton-miles of various commodities which can vary as to specific combinations of physical ton-miles, length of haul, shipment size and so forth.

This specification is moderately restrictive since it implies that the cost-minimizing factor combination is independent of the composition of effective output. Thus, according to this specification, the price of fuel does not affect the combinations of ton-miles and average shipments sizes that can be produced at equal cost with equal length of haul and other attributes.[4/] On the other hand, this property is required if unambiguous quantity comparisons of the outputs of different firms are to be made.[5/]

[4/] As an alternative, we could assume that the cost function is not quality separable and can be described by:

$$C = C(\psi(y,q), q, w)$$

We are presently exploring the implications of this specification.

[5/] Fisher and Shell (1972) develop this condition for the existence of a quantity index.

As indicated above, the value of the function $\psi^i = \psi^i(y_i, q^i)$ serves as the output measure in this specification of the cost function. This assumes that a continuum of different "quality" measures of physical output exists, which can be consistently aggregated by the function $\psi_i(\cdot)$. By analogy with conventional theory of aggregation,[6/] it is natural to require that $\psi(\cdot)$ be homogeneous of degree one in the generic quantity, ton-miles; thus:

$$\psi^i(y_i, q^i) = y_i \cdot \phi(q_1^i, \ldots, q_r^i) \tag{2}$$

This implies that a doubling of physical output at a given quality level doubles ψ the measure of output. No restrictions need be placed on $\phi(\cdot)$.

Because the translog approximation to a cost function permits us to test a wide range of hypotheses concerning the structure of technology, we use it here. As long as firms in the industry are able to adjust capacity easily, we can estimate a long-run cost function,[7/] which takes the following general form:[8/]

6/ See Diewert (1976) and Samuelson and Swamy (1974) on aggregation theory, and Spady and Friedlaender (1976) for the details of the specification of the $\psi(\cdot)$ function.

7/ See Spady and Friedlaender (1976) for a full discussion of these tests in the context of either a long-run cost function or a short-run cost function.

8/ Throughout, we interpret the translog function as an approximation to the true underlying function; we take the sample mean as the point of approximation. This not only affects the interpretation of the coefficients, but in certain cases also substantively affects the results; on this point see Blackorby, Primont and Russell (1977). On related points concerning the effects of scaling and the approximation interpretation, see Denny and Fuss (1975), Christensen and Manser (1977), and Wales (1977).

$$\ell nC(\psi,w) = \alpha_o + \Sigma\alpha_i(\ell n\psi_i - \ell n\bar{\psi}_i) + \Sigma\beta_s(\ell nw_s - \ell n\bar{w}_s)$$

$$+ \tfrac{1}{2}[\sum_i \sum_j A_{ij}(\ell n\psi_i - \ell n\bar{\psi}_i)(\ell n\bar{\psi}_j - \ell n\bar{\psi}_j)$$

$$+ \sum_s \sum_t B_{st}(\ell nw_s - \ell n\bar{w}_s)(\ell nw_t - \ell n\bar{w}_t)]$$

$$+ \sum_i \sum_s C_{is}(\ell n\psi_i - \ell n\bar{\psi}_i)(\ell n\bar{w}_s - \ell n\bar{w}_s) \qquad (3)$$

In addition, we estimate the factor share equations, which take the following form:[9/]

$$\frac{w_s x_s}{C} = \beta_s + \sum_t B_{st}(\ell nw_t - \ell n\bar{w}_t) + \sum_i C_{is}(\ell n\psi_i - \ell n\bar{\psi}_i) \qquad (4)$$

$$s = 1,\ldots,m$$

From the specification of the hedonic output function in Eq. (2) above, we know that

$$\ell n\psi^i = \ell ny_i + \ell n\phi^i(q_1^i,\ldots,q_r^i) \qquad (5)$$

[9/] Note that we can eliminate one of the factor share equations since the mth is implied by the other m-1. The results are invariant to the equation dropped if maximum likelihood methods are used. See Barten (1969) or Berndt and Savin (1975).

We thus utilize a translog approximation of $\phi^i(\cdot)$, and write

$$\ell n\psi^i = a_o^i + \sum_h a_h^i(\ell nq_h^i - \ell n\bar{q}_h^i)$$

$$+ \tfrac{1}{2} \sum_h \sum_\ell b_{h\ell}^i(\ell nq_h^i - \ell n\bar{q}_h^i)(\ell nq_\ell^i - \ell n\bar{q}_\ell^i) \qquad (6)$$

In the most general case, therefore, we substitute Eq. (6) into Eqs. (3) and (4) and jointly estimate these equations, subject to the following constraints, which ensure linear homogeneity of $C(\psi,w)$ in w and the symmetry restrictions implied by cost minimization.[10/]

$$\Sigma\beta_s = 1$$

$$\sum_s B_{st} = 0 \qquad t = 1,\ldots,m; \qquad (7)$$

$$\sum_s C_{is} = 0 \qquad i = 1,\ldots,r$$

$$B_{st} = B_{ts}; \quad A_{ij} = A_{ji}$$

[10/] The FIML procedure in TSP was used for all regressions reported here; it provides a maximum likelihood estimator whose properties are discussed in Berndt, Hall, Hall, and Hausman (1974). Estimating the factor share equations jointly with the cost functions improves the efficiency of the resulting estimates; see Christensen and Greene (1976) on this and related points concerning returns to scale estimation to be covered below. For a development of the homogeneity and symmetry restrictions, and a number of other restrictions useful in testing hypotheses concerning the technology represented by $C(\psi,w)$, see Spady and Friedlaender (1976).

III. Hedonic Cost Functions for the Trucking Industry

As we have indicated above, because trucking output is highly heterogeneous, a single output measure such as ton-miles is inappropriate to use in estimating trucking costs. Not only do different firms carry different commodities; but also, different firms utilize widely different shipment sizes, loads, and lengths of haul. Moreover, firms vary widely in the share of less-than-truckload (LTL) traffic they carry. Thus, two firms, each carrying an equal number of ton-miles over a year can have very different types of output. One could concentrate on short-haul, small load, LTL traffic, while the other could concentrate on long-haul, large-load, truckload traffic. In view of the differences in the composition of their output, it would be highly unlikely if they would have the same costs, although this would be predicted by conventional econometric studies of the trucking industry.

Basically, there are two sources in differences in output for any given measure of ton-miles. First, the nature of the commodities carried may differ; and second, the way in which the commodities are carried with respect to length of haul and size of shipment may differ. Ideally, econometric estimates of trucking costs should take both of these factors into account.

Unfortunately, however, data are not available to give a breakdown of the commodites carried by trucking firms. Nevertheless, by limiting our analysis to regualted carriers of general freight, which typically carry manufactured commodities, we can partially standardize for the composition of output. Moreover, insofar as

insurance costs reflect differences in fragility and costs of special handling, the inclusion of insurances as a quality variables should serve to capture further differences in the composition of output. Thus instead of using a vector of multiple outputs representing each class of commodity, we use a single physical output measure, ton-miles, and use the quality variable, insurance, to capture differentials in the composition of output.

Within regulated carriers of general freight, there are significant interfirm differences with respect to size of shipment, load factor, length of haul, and the share of LTL traffic. Fortunately, data are available to take these differentials into account and we include these variables in the hedonic output function along with insurance.

A. Data

The sample used in this study consists of 168 firms in 1972, located in the Central, Middle Atlantic, and New England trucking regions as defined by the ICC. These firms comprise roughly half of the regional common carriers, but do not include the large interregional carriers. We use the following variables in the cost function:

y = ton-miles (thousands)

q_1 = average shipment size (tons/shipment)

q_2 = average length of haul

q_3 = 1 + percentage of tons shipped in LTL lots[11/]

11/ The variable q_3 was defined as 1 + % LTL, since some firms had no LTL shipments.

q_4 = insurance (insurance cost/ton-miles)

q_5 = average load (tons/truck)

w_1 = price of labor

w_2 = price of fuel

w_3 = price of capital

w_4 = price of purchased transportation

C = total costs

$w_i x_i / C$ = share of factor i.

All of these data were taken from Trinc's Blue Book (1973), which summarizes the individual firm reports to the ICC. The firms' total costs were divided into labor costs, fuel expenditures and fuel taxes, purchased transportation, and other. "Other" expenditures (which included depreciation) were assumed to be payments for capital services; each firm's "carrier operating property--net" was taken as a measure of the quantity of capital (and thus of capital services), so that "other expenditures" divided by "carrier operating property--net" gave a firm-specific price of capital. A firm-specific price of labor was obtained by dividing labor expenditures by the average number of employees. Since direct quantity measures of purchased transportation and fuel were not available, regional prices for these commodities were estimated by a method whose assumptions and results are given in the Appendix.[12/]

The sample of 168 firms included all firms without missing data in five regions (Central States East, Central States West, Middle

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[12/] For similar translog models which use some firm-specific prices and some regional prices, see Christensen and Greene (1976) and Nerlove (1963).

Atlantic, North Middle Atlantic, New England) that met the following conditions:

1. They purchased some of all four factors; but no more than 10 percent of their costs were for purchased transportation. (If a firm does not purchase any of a particular factor, this indicates a corner solution which the specification is incapable of modeling. Firms which rent most of their vehicles do so from subsidiaries set up for tax and regulatory purposes, due to an ICC ruling which allows the deduction of such expenses as current costs, which has the same effect of artificially lowering their operating ratio, which is a primary regulatory target.)

2. They reported an average salary of $8000/year or more per employee. (Some firms implicitly reported salaries as low as $2000, presumably because they counted owner/operators whose trucks they rented as employees, even though they did not directly pay them any wages).

3. They had a calculated price of capital of less than 10. (Due to reasons related to (1) above, a few carriers report almost no operating property, as it is (presumably) owned by subsidiaries. Note that carrier operating property is the value of the property that the firm owns, <u>not</u> its equity in that property.) The mean price of capital in the sample is 2.725 with a standard deviation of 1.287.

4. They had no other "obvious" error in the data. (For instance, one firm reported an average load of 92 tons.)

B. Econometric Results

Because trucking firms should be able to adjust their capital stock in trucks and terminals quite easily, it is likely that they are generally in a situation of long-run equilibrium. We thus estimate a long-run cost function instead of a short-run cost function. In a cross-firm estimate of the cost function, as long as each firm faces the same $\psi(y,q)$ function of the form $\psi(y,q) = y \cdot \phi(q)$, we can estimate a general hedonic cost function given by Eq. (3) and its associated factor share Eqs. (4), with the appropriate substitution of $\ell n\psi(y,q)$, given in Eq. (6).

Because output is conventionally measured solely in physical units, however, it is desirable to determine if the use of the hedonic output function is necessary. We can determine this by setting $\psi = y$ and $\phi(q) = 1$ and estimating a cost function subject to these restrictions. In this case, all ton-miles are treated equally and all of the coefficients in the hedonic output function, given in Eq. (6), are constrained to have a value of zero.

Because conventional cost functions in the trucking industry typically assume a simple homothetic or output-separable technology,[13/] it is also useful to test this assumption. We can do this by imposing the restrictions that all of the coefficients on the factor price and interaction terms are zero. In the context of our cost function, this restriction requires that $C_{\psi i} = 0$, $i = 1,2,3,4$.

Finally, since the question of economies of scale in the trucking industry is important, it is also useful to test for constant returns to scale by imposing the restriction that the cost function is homogeneous of degree 1 in output. In the context of our cost function, this requires that $\alpha_\psi = 1$, $A_{\psi\psi} = 0$ and $C_{\psi i} = 0$, $i = 1,2,3,4$.[14/]

We begin by presenting the general hedonic cost function. The estimate of the $\phi(q)$ function is given in Table 1, while the joint estimates of the cost function and the factor share equations are given in Table 2. Although the $\phi(q)$ function was also jointly estimated

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[13/] See Oramas (1975) for a full review of the literature.

[14/] See Spady and Friedlaender (1976) for a full discussion of these tests.

Table 1

Estimates of $\phi(q_1,q_2,q_3,q_4,q_5)$ by Direct Estimates of $C(\psi,w)$ with $\psi = y \cdot \phi(q_1,q_2,q_3,q_4,q_5)$ †

Coefficient	Variable	Value	Standard Error
a_1	q_1 (Size)	-.0321	.0599
a_2	q_2 (Haul)	-.4294**	.0624
a_3	q_3 (LTL)	1.0314**	.2656
a_4	q_4 (Ins)	.2205**	.0528
a_5	q_5 (Load)	-.2149**	.0885
b_{11}	$\frac{1}{2} q_1^2$	.0071	.0447
b_{12}	$q_1 q_2$	.0323	.0655
b_{13}	$q_1 q_3$	.3438**	.1585
b_{14}	$q_1 q_4$	.0281	.0413
b_{15}	$q_1 q_5$	.0180	.0943
b_{22}	$\frac{1}{2} q_2^2$	.1156	.1403
b_{23}	$q_2 q_3$	-.3337	.4101
b_{24}	$q_2 q_4$	-.0247	.0482
b_{25}	$q_2 q_5$	-.1318	.1293
b_{33}	$\frac{1}{2} q_3^2$	3.7964**	1.7622
b_{34}	$q_3 q_4$	.3756*	.2649
b_{35}	$q_3 q_5$	.5533*	.3834
b_{44}	$\frac{1}{2} q_4^2$	.1907**	.0433
b_{45}	$q_4 q_5$	.2545**	.0660
b_{55}	$\frac{1}{2} q_5^2$	.5022**	.1503

†Jointly estimated with hedonic cost function given in Table 2. Hence R^2 given in Table 2

**significant at 1 percent level

*significant at 10 percent level

Table 2

Joint Estimates of Cost and Factor Share Equations

Coefficient	Variable	Nonhedonic Value	Nonhedonic Standard Error	General Hedonic Value	General Hedonic Standard Error
α_1	constant	8.9428	.0465	9.0806	.0580
α_ψ	ψ	.7640	.0358	1.0367	.0246
β_1	w_1	.5872	.0050	.5939	.0050
β_2	w_2	.0414	.0013	.0389	.0014
β_3	w_3	.3344	.0041	.3317	.0041
β_4	w_4	.0370	na	.0355	na
B_{11}	$\frac{1}{2} w_1^2$	.0133	.0153	.0214	.0164
B_{12}	$w_1 w_2$	-.0082	.0055	-.0213	.0056
B_{13}	$w_1 w_3$	-.0076	.0086	-.0066	.0090
B_{14}	$w_1 w_4$	.0025	na	.0065	na
B_{22}	$\frac{1}{2} w_2^2$	.0065	.0063	.0320	.0062
B_{23}	$w_2 w_3$	-.0064	.0020	-.0128	.0020
B_{24}	$w_2 w_4$	.0081	na	.0021	na
B_{33}	$\frac{1}{2} w_3^2$	.0122	.0077	.0188	.0075
B_{34}	$w_3 w_4$	.0262	na	.0006	na
B_{44}	$\frac{1}{2} w_4^2$	-.0318	na	-.0092	na
$C_{\psi 1}$	ψw_1	-.0006	.0035	.0091	.0045
$C_{\psi 2}$	ψw_2	-.0008	.0009	-.0022	.0013
$C_{\psi 3}$	ψw_3	-.0042	.0028	-.0094	.0036
$C_{\psi 4}$	ψw_4	.0040	na	.0025	na
$A_{\psi\psi}$	$\frac{1}{2} \psi^2$	.1079	.0323	.0170	.0298

Table 2 (Continued)

	Nonhedonic	General Hedonic
Log of Likelihood Function	1053.72	1186.53
R^2		
Cost Equation	.7491	.9427
Labor Equation	.0188	.0497
Fuel Equation	.0271	.0378
Capital Equation	.0225	.0534

with the cost and factor share equations, it is useful to present it separately.

A constant does not appear in Table 1, since its effect in this specification would be merely to change the units of measurement of $\psi(q)$. The insignificant linear sign of the shipment size term indicates that shipment size has no direct impact on effective output, while the significantly negative signs in the linear load and haul terms indicate that ton-miles characterized by larger loads and longer lengths of haul are easier to produce than ton-miles characterized by smaller loads and shorter lengths of haul. Conversely, the significantly positive coefficients in the linear LTL and insurance terms indicate that ton-miles characterized by a large percentage of LTL shipments and fragile or high-value commodities, which are subject to high insurance costs, are harder to produce than those characterized by a small percentage of LTL shipments and relatively low-value or durable commodities. Thus these findings indicate that high-value or fragile LTL shipments that are characterized by small loads and short hauls are costlier to produce than low-value truckload shipments that are characterized by large loads and long hauls, for any given amount of ton-miles.[15/]

[15/] Specifically, the linear coefficients give the elasticity of effective output with respect to quality at the sample mean. Thus a positive sign in the linear terms implies that, cet.par., an increase in the quality will increase the effective output, and thus increase costs. Similarly, a negative sign in a linear coefficient implies an increase in the quality will reduce effective output and hence costs.

Table 1 indicates that squared and interaction terms for LTL, insurance, and average load are generally significant and positive, while those for shipment size and haul are not. This indicates that effective output or costs will increase more than proportionately as the percentage of LTL increases, the amount of fragile commodities increases, or the average load increases.

Table 2 presents the joint estimates of the cost and factor share equations using the general hedonic cost function. We see that the overall R^2 is very high as is that of the cost equation. Although the R^2's of the factor share equations are quite low, this is not unusual in translog cost studies (see Denny and Fuss (1975)). Moreover, the estimation method employed does not simply minimize the sum of squared residuals, but also takes into account their covariance across equations; R^2 is merely a descriptive statistic in this context. Since factor demands are closely related to costs and outputs, it is likely that factor demand equations would yield considerably higher R^2's. Thus, while the equations do not yield particularly good results in terms of shares, it is likely that they would be considerably better in terms of actual factor utilization.

Table 2 also presents the joint estimate of a conventional nonhedonic cost function, which is obtained by setting $\phi(q) = 1$. Both the R^2 and the log of the likelihood function of the nonhedonic cost function are substantially less than the comparable statistics in the general hedonic cost function. This indicates that not using a hedonic output function is a serious specification error.
The magnitude of this error should be clear from the generally

significant coefficients that were associated with the $\phi(q)$ functions, estimated in Table 1. Table 3 gives more precision to these results by performing the likelihood ratio test on the restricted and unrestricted cost functions and indicates that we must reject the specification of the nonhedonic cost function at the .00001 level of significance.

It is also useful to test for separability and constant returns to scale in the hedonic and nonhedonic cost functions. The results of these tests are also given in Table 3 and indicate that if one used a nonhedonic cost function, one would marginally reject the assumption of homotheticity and strongly reject the assumption of constant returns to scale. In constrast, in using the hedonic formulation, one would clearly reject the homotheyicity assumption and only marginally reject the hypothesis of constant returns to scale.[16/] These findings not only indicate that the use of conventional output measure represents a serious misspecification, but also that it can lead to highly erroneous conclusions about the structure of technology. Because these findings have important implications for policy, it is useful to explore them in some detail.

C. Implications

We now discuss the implications of the hedonic and nonhedonic cost functions for returns to scale and factor demands.

1. Returns to Scale

In recent years, the trucking industry has been marked by a large number of mergers and acquisitions, in which large firms have either acquired or merged with smaller firms to extend their operating rights.

[16/] Conditional upon homotheticity, constant returns to scale is accepted.

Table 3

Summary of Tests for Homotheticity and Homogeneity in Output

	Log of Likelihood Function	Hypothesis Outcome	Significance Level
General Hedonic	1186.53		
Restricted for Homotheticity	1181.89	Reject Homotheticity	.025
Restricted for CRS	1181.38	Reject CRS	.070
Nonhedonic	1053.72	Reject Nonhedonic	.0001
Restricted for Homotheticity	1050.42	Reject Homotheticity	.090
Restricted for CRS	1034.07	Reject CRS	.0001

Thus the industry has not only become more concentrated, but large firms have also become significantly larger. Since trucking firms essentially face a regulated price, this indicates that they perceive the existence of rather marked economies of scale; for a given regulated rate structure, a larger scale of operations should yield lower costs

and higher profits. Thus members of the trucking industry feel that in the absence of regulation, the industry would become highly concentrated as firms try to exploit the perceived economies of scale.

In contrast, economists generally believe that the trucking industry would be competitively organized in the absence of regulation. Since the trucking industry is characterized by low capital requirements, they feel that there is nothing inherent in the structure of technology that would indicate the existence of barriers to entry or economies of scale. Thus, in the absence of regulation, one would expect the trucking industry to be characterized by a large number of small firms, each operating at the minimum point of its average cost curve.

The estimates of nonhedonic and hedonic specification of the cost functions given in Table 2, above, do much to shed light on this controversy, since the nonhedonic cost function indicates the presence of rather dramatic economies of scale, while the general hedonic cost function indicates the presence of mild diseconomies of scale.

While is is not possible to strictly characterize returns to scale for a nonhomothetic production structure, it is possible to gain some intuition concerning this issue if we limit the analysis to situations where relative factor prices are constant, since in this case we can infer the shape and location of the average cost curve from the $A_{\psi\psi}$ and α_{ψ} coefficients. Specifically, at mean factor prices, a positive $A_{\psi\psi}$ indicates that the firm faces a U-shaped average cost curve (a negative $A_{\psi\psi}$ would indicate an inverted-U average cost curve; $A_{\psi\psi} = 0$ indicates an average cost curve which is either exponentially falling, rising, or constant, depending on α_{ψ}); if $\alpha_{\psi} = 1$, then the bottom of the U, the point of minimum average cost, occurs at $\psi = \overline{\psi}$,

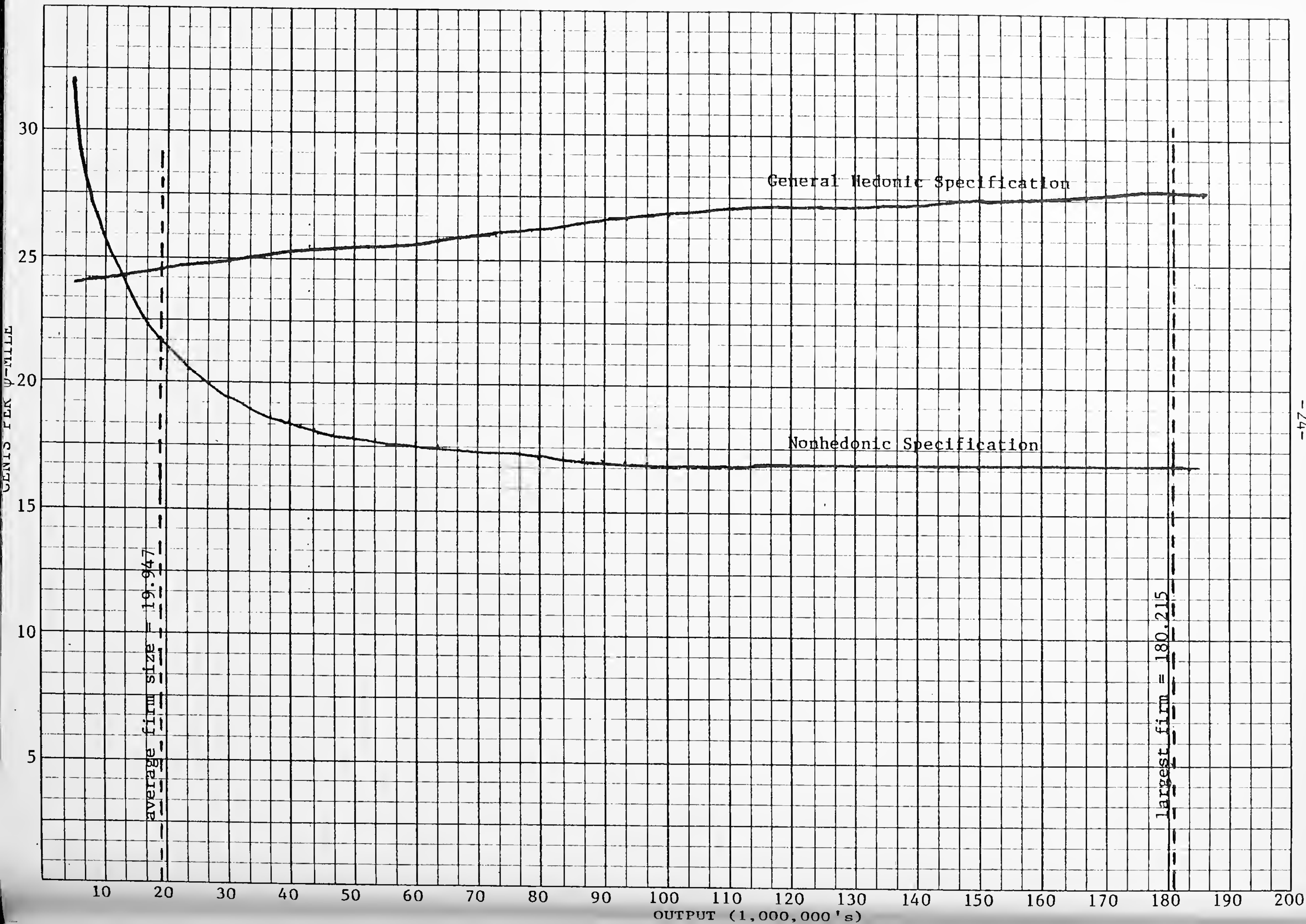
the mean output level. If $\alpha_\psi < 1$, the point of minimum average cost occurs at $\psi > \bar{\psi}$, since expanding output beyond $\bar{\psi}$ would steadily decrease average costs if $A_{\psi\psi}$ were 0, but for $A_{\psi\psi} > 0$, additional costs grow with $(\ell n\psi - \ell n\bar{\psi})^2$ until they dominate the effects of the α_ψ term. Similarly, if $\alpha_\psi > 1$, then the point of minimum average cost occurs at $\psi < \bar{\psi}$.

In the case of the nonhedonic cost function, $A_{\psi\psi} = .1079$ and $\alpha_\psi = .7640$, while in the case of the general hedonic cost function, $A_{\psi\psi} = .0170$ and $\alpha_\psi = 1.0367$. Thus the nonhedonic cost function indicates that the average cost curve is U-shaped and that its minimum point lies well beyond the mean output level, suggesting the existence of economies of scale. In contrast, the hedonic cost function indicates that, if anything, costs are exponentially rising (since $A_{\psi\psi}$ is not statistically significantly different from zero).

Figure 1 plots the average cost functions for the nonhedonic and hedonic cost functions, which show the striking differences in economies of scale. The nonhedonic cost function indicates that costs fall until outputs of 100 million ton-miles are reached and then remain virtually constant. In contrast, the hedonic cost function indicates that costs rise steadily throughout the relevant range of output.

These differences can be reconciled when one realizes that ton-miles are not equal and that larger firms typically have larger lengths of haul, larger loads, and smaller proportions of LTL traffic. Thus, the effective ton-miles of large firms are less costly to produce than the effective ton-miles of small firms. Consequently, firms have a clear incentive to merge if by so doing they can increase the efficiency of their operations by increasing their

FIGURE 1


General Hedonic Specification
Nonhedonic Specification
average firm size = 19.947
largest firm = 180.215
CENTS PER ¢-MILE
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
OUTPUT (1,000,000's)

shipment size or length of haul or by reducing their share of LTL traffic. This, in large part, explains why many of the mergers have consisted of large firms merging with smaller ones that fill in missing portions of their operating rights.

Thus, insofar as larger firms can achieve greater economies of density and utilization than smaller firms, we can understand the large number of mergers that have taken place in the trucking industry in recent years. Nevertheless, it is important to realize that these are not economies of scale in the conventional sense, but rather economies of density and utilization. If smaller firms could operate with the same loads, lengths of haul, and share of LTL traffic as larger firms, there would be little incentive to merge.

Since present regulatory restrictions upon operating rights limit firms to the commodities they can carry and the routes they can travel, firms presently have a clear incentive to obtain new operating rights. These, however, are easier to obtain through merger and acquisition than through the granting of new authorities. Hence present regulatory practices provide a clear incentive for firms to merge.

Because diverse operating rights permit firms to utilize equipment more efficiently and undertake longer hauls per trip, it is likely that any observed economies of scale are of a regulatory rather than a technological nature. In particular, larger firms have lower costs because they have longer lengths of haul, and it is likely that they have longer lengths of haul because they have more diverse operating rights than their smaller competitors. Consequently, in the absence of entry and operating restrictions it is likely that

small firms would be able to enjoy the same economies of haul enjoyed by large firms. Thus it is unlikely that the cost structure of different sized firms would be significantly different.[17/]

2. Factor Demands

It is also possible to estimate the elasticities of substitution among factors and their own price elasticities from the coefficients in Table 2. The Allen-Uzawa elasticities of substitution are defined as[18/]

$$AUES_{ij} = C\,C_{ij}/C_i C_j$$

where the subscripts denote differentiation with respect to a factor price. These give the elasticity of demand for factor i with respect to factor j's price weighted by the inverse of factor j's cost share. These elasticities are given in Table 4 for a hypothetical firm producing average quality-standard ton-miles from inputs available at average prices, $\bar{w}_i$. Own price elasticities of factor demands are also given in Table 4. Note that a negative elasticity of substitution implies that factors are complements, while a positive elasticity of substitution implies that factors are substitutes.

Table 4 indicates that the factor elasticities implied by the nonhedonic and the hedonic specifications are generally similar.

[17/] See Friedlaender (1977) for a more detailed discussion of economies of scale.

[18/] See Berndt and Wood (1974) for their derivation in a translog framework.

Table 4

Estimated Elasticities of Substitution

Implied by Cost Functions

Elasticities of Substitution	Nonhedonic Elasticity	General Hedonic Elasticity
Labor-Fuel	.6627	.0780
Labor-Capital	.9613	.9665
Labor-Purch. Trans.	1.1151	1.3083
Fuel-Capital	.5377	.0030
Fuel-Purch. Trans.	6.2879	2.5207
Capital-Purch. Trans.	3.1175	1.0509
Own Price Elasticity		
Labor	-.3902	-.3701
Fuel	-.8016	-.1385
Capital	-.6291	-.6118
Purch. Trans.	-1.8225	-1.2236

We thus see that each factor is a substitute with all other factors. Consequently, increases in the price of any one factor will cause substitutions toward all other factors.

It is intersting to note, however, that the hedonic regression implies virtually no substitutability between fuel and capital or labor and an extremely low price elasticity of fuel, while the nonhedonic regression implies a reasonable degree of substitutability between fuel and these factors and a rather high own price elasticity of fuel. Thus if we used the nonhedonic regression, we would (incorrectly) infer that increases in fuel prices would lead to substitutions away from fuel. In contrast, the hedonic regression indicates a virtually inelastic demand for fuel. Thus efforts to encourage energy conservation through increases in fuel prices would probably meet with little success among the regulated common carriers.

Table 4 also indicates that purchased transportation is highly substitutable with the other factors and that its own price elasticity is quite high.

IV. Summary and Conclusions

This paper has indicated that conventional econometric estimates of trucking cost functions are not very reliable and hence not very useful for policy purposes for two fundamental reasons: First, the output of the trucking firm is heterogeneous by its very nature. Hence, simple measures of output such as ton-miles will fail to capture the true relationships between cost and output. Second, it is likely that the trucking firm is subject to nonhomothetic production. Hence, efforts to describe technology by a simple homothetic production function, such as the Cobb-Douglas or the CES production functions, may yield seriously biased estimates.

To test these hypotheses, we developed a general quality-separable hedonic cost function that permitted nonhomothetic production and quality adjustments, and estimated it using a cross section of 168 firms in the Eastern United States in 1972. This (and similar) hedonic regressions indicated the following results, which have important policy implications.

1. The level of service in terms of length of haul, size of load, composition of output, and share of LTL traffic does affect costs. In particular, evidence of increasing returns to scale exists when ton-miles is used as an output measure, but fails to exist when output is adjusted for quality differentials. This implies that any economies that might exist are economies of density or of service, not economies of scale of output *per se*.

2. When measured in terms of quality-adjusted output, trucking firms appear to face mildly increasing costs over a wide range of factor prices. This indicates that large firms would face substantially higher costs in the absence of the economies of utilization they presently enjoy due to existing regulatory restrictions. Thus, *ceteris paribus*, the largest firms should be discouraged from further expansion.

3. There are substantial nonhomotheticities in the structure of trucking firms' production. Consequently, any attempt to model their technology using a homothetic cost or production function (such as the Cobb-Douglas or the CES) is a serious misspecification. The nonhomotheticities make global generalizations about returns to scale impossible, though they are not so large that the general character of scale returns is seriously altered for reasonable (with an order of magnitude of the mean) relative prices. As scale expands, factor shares change: large firms spend proportionately less on fuel and capital, and more on labor and purchased transportation; but these effects are small.

Thus, these results clearly indicate the perils of conventional econometric estimates of trucking costs. If production is joint and if output is heterogeneous, we clearly want to take these facts into account in specifying cost functions. Otherwise, we may make the wrong policy decisions based on the biased estimates that result from misspecified cost functions.

APPENDIX

The Estimation of Regional Factor Prices

The basic problem in establishing prices for both purchased transportation and fuel is that while each firm's total expenditures on these goods are observed, the quantities purchased are not. Instead, an indirect measure of quantity purchased is available.

For fuel, for instance, we know the firm's vehicle-miles with firm-owned trucks, and the number of vehicle-miles rented with and without drivers. Since vehicles rented with drivers typically include fuel within the rental price, these miles are subtracted from the total to obtain the vehicle-miles for which the firm provided fuel.

Using this mileage figure, a fuel cost per vehicle-mile can be calculated for each firm; this would be an appropriate fuel price measure if every vehicle got the same mileage per gallon. An inspection of these figures, however, reveals that if this were true, fuel prices varied between firms by a factor exceeding ten. It is clear that a constant miles-per-gallon assumption is inappropriate.

The factors that would appear to most directly affect fuel mileage are vehicle size, the percentage of miles driven on interstate highways, and the number of stops (and, therefore, presumably side trips to more congested areas) made. Reasonable proxies for these variables are average load, average length of haul, and the percentage of tons shipped in LTL lots. Thus, as an identity we have:

$$\frac{\text{FUEL \$}}{\text{VEH.MILE}_{i,r}} = \frac{\$}{\text{FUEL GALLON}} \cdot \frac{\text{FUEL GALLONS}}{\text{MILE}}$$

$$= P_r \cdot \phi(QLH_i, \ AVLOAD_i, \ LTL_i) \tag{A.1}$$

where P_r is the price of fuel in region r and i subscripts denote firm specific variables. While a number of stochastic specifications of (A.1), some of them very complicated, suggest themselves, the simplest is:

$$\frac{\text{FUEL \$}}{\text{VEH.MILE}_{i,r}} = P_r \cdot \phi(ALH_i, \ AVLOAD_i, \ LTL_i) + \varepsilon_i$$

where the ε_i's are normal and i.i.d.[1/] The gallons/mile function $\phi(ALH_i, \ AVLOAD_i, \ LTL_i)$ is approximated by a translog function, and its parameters and the P_r's are estimated by applying FIML to:

$$\frac{\text{FUEL \$}}{\text{VEH.MILE}_i} = P_r \cdot e^{\ell n\phi(ALH_i, AVLOAD_i, LTL_i)} + \varepsilon_i \tag{A.2}$$

where $\ell n\phi = \alpha_1(\ell n \, ALH_i - \ell n \, \overline{ALH}) + \alpha_2(\ell n \, AVLOAD_i - \ell n \, \overline{AVLOAD})$

$$+ \alpha_3(\ell n \, LTL_i - \ell n \, \overline{LTL}) + \tfrac{1}{2}\beta_{11}(\ell n \, ALH_i - \ell n \, \overline{ALH}) \tag{A.3}$$

$+$ etc...

1/ For the results given below, there is little evidence of regional heteroscedasticity; beyond this, the specification of the disturbance has not been further analyzed.

The resulting estimates are given in Table A.1.

In interpreting the price estimates, it must be remembered that they include fuel taxes, which do differ by region, and that they are for 1972, before the August 1973 Arab oil boycott, which raised prices more in New England than in other regions. The comparatively small standard errors of the regional price estimates relative to the estimated inter-regional differences, combined with our strong prior belief in such differences, makes these estimates plausible.

Furthermore, the estimates of the gallons/mile function accord extraordinarily well with prior expectations. In the approximation interpretation of the translog function, primary importance is placed on the linear terms, which give the elasticity of gallons/mile with respect to ALH, AVLOAD, and LTL. In each case, these elasticities have the expected sign and are significantly different from zero. The significant second-order terms, which are the LTL cross-terms, indicate increasing sensitivity of fuel requirements to the percentage of LTL cargo as that percentage increases. The AVLOAD and ALH cross-terms indicate that this effect is ameliorated for large loads and long hauls. The overall picture that these results imply is that firms specializing in small short-haul LTL shipments require more fuel per vehicle-mile.[2/]

Purchased transportation includes expenditures for rail, air, water, and truck transportation; in our sample of 168 firms, 101 firms reported

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[2/] Note that this result need not conflict with the quality-separability assumption made in estimating the cost function, which requires that, <u>ceteris paribus</u>, the amount of fuel used per unit of <u>effective output</u> be constant. A lightly-loaded vehicle-mile with short haul LTL shipments produces more effective output.

Table A.1

Maximum Likelihodd Estimates of Regional Fuel Prices

Coefficient	Value	Standard Error	
PRICE, NEW ENGLAND	.03027	.00350	
PRICE, NORTH MID ATLANTIC	.03163	.00219	
PRICE, MIDDLE ATLANTIC	.03968	.00287	NATURAL TERMS
PRICE, CENTRAL STATES EAST	.03027	.00246	
PRICE, CENTRAL STATES WEST	.03503	.00229	
AVERAGE LENGTH OF HAUL	-.55681	.08263	
AVERAGE LOAD SIZE	.68227	.08231	
LTL[1]	.90247	.21638	
$(ALH)^2$	.07472	.25347	
$(AVLOAD)^2$	.27682	.19935	LOGARITHMIC TERMS
$(LTL)^2$	7.9851	1.91951	
AVLOAD • ALH	-.09373	.18868	
LTL • AVLOAD	-.80628	.42677	
LTL • ALH	-1.28609	.42166	

Dependent variable is fuel expenditures/vehicle-mile.

$R^2 = .5298$

SSR = .0358149

LOG LIKELIHOOD FUNCTION = 481.637

OBSERVATIONS = 168

[1]Throughout, LTL = 1 + % of tons in LTL shipments, so that LTL ≠ 0 even if all shipments are of truckload size.

zero expenditures on the first three categories. For these 101 firms purchased transportation includes vehicle-miles rented with and without driver. Unfortunately, for these vehicle-miles separate figures for average load, average length of haul, LTL percentage and average shipment size are not available; it is necessary to assume that the firm's average values for these variables are reasonable representations of the characteristics of the rented vehicle-miles. As in the estimations of fuel prices, average load is a proxy for vehicle size, average length of haul is a proxy for the percentage of miles driven on interstate highways, and the LTL percentage is taken to measure the number of stops and side trips into relatively congested areas. Clearly, when vehicle rental includes a driver, length of haul and the number of stops affects the cost of a rented vehicle-mile, and these factors may be relevant even when the firm supplies its own driver insofar as they affect elapsed time per vehicle-mile. Finally, of course, the percentage of miles rented with driver is an important determinant of cost per rented vehicle-mile.

As the estimating procedure for an additive error specification similar to (A.2) did not converge, OLS was applied to the following multiplicative error specification:

$$\ln \left(\frac{\text{PURCH. TRANS \$}}{\text{RENTED VEH-MILES}}\right)_i =$$

$$\ln P_r + \ln\phi(\text{ALH}_i, \text{AVLOAD}_i, \text{RWD}_i, \text{LTL}_i, \text{AVSIZE}_i) + \varepsilon_i \qquad (A.4)$$

where $\phi(\cdot)$ is a translog function similar to (A.3). The results are reported in Table A.2, with $e^{\ln \hat{P}_r}$ reported as the estimated regional

Table A.2

Maximum Likelihood Estimates of Regional Purchased Transportation Prices

Coefficient	Value	Standard Error	
PRICE, NEW ENGLAND	.80428	.68367	
PRICE, NORTH MID-ATLANTIC	.44628	.35651	
PRICE, MIDDLE ATLANTIC	.63825	.45465	NATURAL TERMS
PRICE, CENTRAL STATES EAST	.44491	.31279	
PRICE, CENTRAL STATES WEST	.58268	.58082	
AVERAGE LENGTH OF HAUL	-1.76340	.76774	
AVERAGE LOAD SIZE	2.80647	1.06506	
LTL	3.59209	2.40609	LOGARITHMIC TERMS
(1 + % RENTED WITH DRIVER)	2.26464	1.02241	
AVERAGE SHIPMENT SIZE	.02760	.38326	

Cross-terms with coefficients exceeding their standard error:

LTL^2	43.44850	29.30990
LTL • AVLOAD	10.36130	7.33880
LTL • AVSIZE	5.08065	3.30844
AVSIZE • AVLOAD	2.24518	1.38405

Dependent variable is log (purchased transportation expenditures (rented vehicle-mile)

R^2 = .3580

SSR = 126.896

LOG LIKELIHOOD FUNCTION = - 154.839

OBSERVATIONS = 101

purchased transportation prices;[3/] their standard errors are calculated from the usual first-order Taylor expansion formula. The non-price coefficients are on logarithmic terms as implied by (A.4); the numerous insignificant cross-terms are not reported.

In general, the linear non-price coefficients are of the predicted sign and significant; average shipment size, a possible alternative proxy for vehicle size, has no effect. The price terms, however, do not seem as reasonable as in the fuel case: New England's price exceeds that of Central States East by 80%. In view of the large standard errors, it would not be surprising if the restriction of (A.4) to a single price for purchased transportation could not be rejected at the usual levels. On the other hand, it may well be that the purchased transportation market was indeed different from the other regions: comparatively few New England firms are among those excluded from the sample due to extraordinarily high purchased transportation shares, while a large proportion was excluded for having no expenditures on purchased transportation. Both these factors indicate a less well-developed market for purchased transportation in New England, which would be consistent with a higher price. Thus, in the absence of good reasons to treat the regions identically, the estimated purchased transportation prices have been used in our cost functions.

[3/] Under the assumption that the disturbances in (A.4) are normal i.i.d., the estimated prices reported in Table A.2 are maximum likelihood estimates.

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